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THE ACCORDANCE OF SUMMIT LEVELS AMONG ALPINE MOUNTAINS: THE FACT AND ITS SIGNIFICANCE¹

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THE STATEMENT OF SUMMIT-LEVEL ACCORDANCE

Neither statistics nor eloquence are required to recall one principle in the interpretation of lofty, alpine mountains; their student must be content to attack their mighty problem in a piecemeal fashion. The alps of the world are tangles in structure and the stony records of tangles of prodigious events. It is no wonder that their form has so long baffled the evolutionist. He has often had to turn back from the attempt to carry into the high mountains the same ground principles of land-building and land sculpture which have of late years been so successfully explaining the simpler forms of the land.

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If, then, advance in the interpretation of the world's great ranges can be really made in any one direction, such advance must be welcomed as a step toward the distant, ultimate goal of complete knowledge of the earth. Not only for the sake of the single study itself, but perhaps still more for the sake of putting no obstacle in the way of related interpretations, it is well that close scrutiny be fixed on every such subordinate theory. No further reason is necessary for additional field-work on a problem now in discussion concerning the physiography of mountains, namely, the meaning of the generally observed accordance of levels among the higher summits of an alpine range.

The word "accordance" is used advisedly. "Equality" of heights is not meant by those observers who have given the question the best attention. For limited areas "subequality" of the summits is a fact, but over wider stretches, and especially over the whole of a single range, even subequality fails, and the accordance takes the form of sympathy among the peaks whose tops in companies or in battalions rise or fall together in imaginary surfaces often far removed from the spheroidal curve of the earth. In general, the imaginary surface which will include the higher summits of peaks and ridges in an alpine range has the form of a low arch, highest in the interior of the range and elongated in the direction of the main structural axis of the range. Subordinate, but usual and systematic, complications in the form of this imaginary surface are found in transverse crenulations which alternately depress and raise the surface from its average out-sloping position on the margin of the great arch. The axes of these transverse depressions are often suspiciously coincident with existing drainage courses.

There is, then, at least one orderly element in the "chaos" or "tumbling sea" of mountains visible from a dominating point in any one of a goodly number of alpine ranges. The accordance of summit altitudes has been noted in the Alps, in parts of the Caucasus, in the Pyrenees, in the Sierra Nevada of California, in the Alaskan ranges, in the Canadian Selkirks and Coast Range, and in the American Cascade Range.¹

¹ In the present paper the term "alpine range" is used to signify a range possessing not only the rugged, peak-and-sierra form of the Swiss Alps, but, as well, the internal

The fact of accordance is established, while the theories of explanation are very various. That they need critical examination and sifting is clear, not only for the sake of the important fact of accordance itself, but also for the reason that these theories involve widely diverging views on great physiographic revolutions. Geological history in long chapters is thereby as expressly implied as it would be by the interpretation of purely stratigraphic evidences, illustrating over and over again the truth that both classes of evidences are required in building up a complete history of the earth. Not only do these theories involve premises regarding great denudations, but, as well, a multitude of details concerning river history and the evolution of individual mountain massifs. There are likewise involved correlative views of the physiographic development of the neighboring regions, both on the large scale and in details. Geographic description and nomenclature should be controlled by reference to the correct theory or theories of land-form origins. Finally, large conclusions concerning the origin of the force of mountain uplift must follow in the wake of certain of the hypotheses already announced to explain the phenomenon of accordance in summit levels. The attempt has even been made to connect the origin of fractures and of mineral veins with the specialized kind of crustal movement hypothesized by one explanation of this accordance.¹ There are thus abundant reasons for coming to a wise decision as to the best explanation of the fact.

THE VARIOUS EXPLANATIONS OF ACCORDANCE

The hypotheses dealing with this sympathetic attitude of alpine summits may be classified on the basis of the logical explanation of an organism. (a) How far is the feature in question due to *inheritance*? (b) How far is it due to *spontaneous development* in the present environment? A review of the hypotheses shows, everywhere and naturally, emphasis placed on erosion, but the writer believes that the possibilities of inheritance are only partially worked structures incidental to intense crumpling, metamorphism, and igneous intrusion as exemplified in the Swiss Alps.

¹ A. C. Spencer, *Transactions of the American Institute of Mining Engineers*, October, 1904, p. 35.

out, and, again, that the methods of spontaneous development are not yet brought into the proper balance for final discussion or decision on the question.

I. EXPLANATIONS BY INHERITANCE

The accordance of summit levels may well suggest the analogy of moderately or maturely dissected plains underlain by rocks of horizontal structure. Often with such plains there is little or no doubt of the original, simple form before erosion had produced the intaglio forms of dissection. The common agreement of altitudes among the hilltops of the sculptured plain is manifestly the effect of inheritance from the early, initial stage of the plain's history. Is there anything comparable in the derivation of existing alpine mountain ranges? Their almost infinite complexity of structure due to folding, blocking, thrusting, igneous intrusion, and metamorphism forbids that the analogy shall be anything more than an analogy; yet the question is raised whether, at some earlier stage in the history of each range, there may not have been produced a more or less perfect accordance of summit levels which would, through ordinary processes of erosion, furnish similar accordance in the later stages of the history, including the present stage. Three answers may be proposed to the question.

1. *The peneplain theory.*—The explanation which has, on the whole, won most attention from American students of the problem is that now familiar to physiographers as the peneplain theory. By this view the alpine range is supposed to have passed through the paroxysmal epoch of uplift by crumble, faulting, and thrusting; then through a period of denudation so prolonged that the once lofty range was thereby reduced to a gently rolling lowland, the surface of which stood near sea-level or the general base-level of the region. In every full published discussion the author favoring the peneplain theory has regarded it as probable or as certain that subordinate residual hills or mountains, monadnocks, rose above this peneplain.

A second chief premise necessary to the theory is that of a broad, massive warping of the peneplained surface; the major axis of upwarp being roughly coincident, or parallel, with the present topographic axis of the range. The existing details of relief are then regarded

as due to inheritance, after mature erosion, from the initial peneplained surface with which the present physiographic cycle opened. The sculpture of the unwarped surface is by some attributed largely to streams definitely controlled in their direction of flow by the general slopes of the warped peneplain, i. e., consequent streams. In the Cascade Range of Washington, Messrs. Willis and Smith make the special supposition of transverse upwarps and downwarps complicating the initial form of the uplifted Pliocene peneplain from which the present range is supposed to have "descended." Mr. Spencer has deduced peneplanation and arch-warping for the Coast Range of British Columbia. He is therewith compelled to place in a different, antecedent, class a half-dozen of the chief rivers cutting clear across the range.¹ Revived subsequent streams—that is, those developed on weak rock-belts during peneplanation and incited to still deeper cutting on those belts by the upwarping—must form a third kind of corrosive agents. Following the upwarping, local and general glaciation will still further greatly complicate the scheme of drainage.

One may feel but little doubt that the peneplain theory is sound when applied to the more or less classic cases of the Appalachian Piedmont, the New Jersey, New England, and Acadian plateaus, the plateaus of the Rhine, of Bohemia, and of central France and Brittany. In each one of these instances the already well-discussed criteria of the uplifted and sculptured peneplain are apparently well satisfied. Each region shows excellent examples of the remnant, high-lying plateau flats truncating rocks of complex structures. Often the criterion of adjusted drainage is admirably fulfilled. Where glaciation has not disturbed the normal conditions, the plateau remnants of the former lowland still bear the deep residual soils expected on the theory. Finally, in none of these regions is the geological history of adjacent physiographic provinces discordant with the peneplain theory.

If any one of the criteria can be taken as more positive than the others, it is that of extensive plateau remnants of the peneplain surface. Yet it is clear that even those remnants will lose their flat-topped character with prolonged erosion. The perfectly mature

¹ *Bulletin of the Geological Society of America*, Vol. XIV (1903), p. 125.

dissection of the former lowland will greatly weaken the proofs of approximate planation near base-level at the end of a former physiographic cycle. It is expected, however, that subequality of accordance of summit levels will long characterize the individual mountains produced by the intaglio cutting of the upwarped peneplain. Conversely, where such accordance of summit levels in structurally complex mountains is found, it is legitimate, if not necessary, to place ancient peneplanation as a possible stage in the topographic evolution.

This has been the principal criterion on which Messrs. Russell, Smith, and Willis have based wide-reaching conclusions regarding the development of the main Cascade Range of Washington. Mr. Willis has mapped a few, very small, flattish areas on summits which he considers as possible remnants of the peneplain.¹ Mr. Smith states that no remnant of it has been discovered in the large area of the Snoqualmie Quadrangle (U. S. Geological Survey map) which he has particularly studied.² Mr. Russell came to a similar conclusion regarding the high Cascades of northern Washington.³ Geology and physiography owe much to these authorities for their systematic and masterly presentations of the theory which every worker in the general geology of the Cascades must entertain and carefully discuss. The problem is there, as in other similar ranges, peculiarly difficult because it is precisely in mountains of alpine height that the records of former peneplanation are most quickly rubbed out; it is there that positive criteria are reduced to a minimum. One must therefore especially welcome such constructive work as is represented in the memoirs recently published concerning a typical alpine range, the high Cascades.

The peneplain theory does certainly render the accordance of summit levels among alpine peaks intelligible. Yet that fact is far from proving the truth of the theory as applied to alpine ranges. This will be especially clear if it can be shown that there are, and have been, other agencies at work capable of producing the actual degree of accordance in the summit levels of such a range as the high Cascades. The writer believes that further constructive work along

¹ *Professional Paper No. 19*, U. S. Geological Survey (1903), Plates 16 and 17.

² *Ibid.*, p. 34.

³ *Twentieth Annual Report*, U. S. Geological Survey, Part II (1900), p. 141.

the lines of the peneplain theory is at present not so necessary as a critical inquiry into alternative hypotheses. For the same reason, a concrete criticism of the views on which have been based the attempts to establish the peneplain theory for special alpine ranges will here be left in abeyance.

The other possible explanations of accordance, including those already published as well as others which have occurred to the writer in the course of field-work, have one important feature in common—a feature which places all of them in opposition to the peneplain hypothesis. That hypothesis demands at least two cycles of erosion in the history of the mountain range; one cycle essentially completed at the time of penultimate extinction of relief, with a second cycle, the present one, advanced to the mature stage of dissection. Involved with this premise of multiple cycles is the conception that the present cycle has been initiated by a quite different kind of mountain-building from that which first gave the range its great altitude. Broad, relatively gentle warps, producing on the average an arch elongated in the axis of the existing range, form the kind of movement demanded in the uplift of the peneplaned area, while intense plication, thrusting, and blocking gave the range its internal structures and its original relief. In short, the peneplain hypothesis stands in contrast with all the other hypotheses in placing peneplanation and subsequent warping among the necessary stages in the development of the existing mountains. Unequal in strength as these alternative hypotheses may be, they have the common characteristic of excluding a great denudation and a specialized kind of crustal movement from the list of complications in the history of the range. It is most important to observe that this common characteristic, coupled with the fact that the alternative explanations are not mutually exclusive, gives them cumulative force against the peneplain hypothesis, when applied to truly alpine mountains.

2. *Hypothesis of original rough accordance of summit levels, due to isostatic adjustment.*—Basal to all of the alternative hypotheses is the inquiry as to the original form of the range at the geological moment when paroxysmal folding of its rocks was practically completed. It is self-evident that the term "original" is here used arbitrarily, but the strain on language may be permitted in thus conven-

iently naming and emphasizing a principal epoch in the early history of the range.

At first sight one may be surprised to find this accordance of summit levels among high mountains of complex structure. Surprise should be tempered, however, by the consideration that the original relief was not even approximately determined by constructional profiles deducible from existing structures.

It is, for example, highly improbable that the "reconstruction" of a great alpine anticline through a study of its denuded roots can represent the original height of its crest above sea-level. Nor is it legitimate to conclude from the great shortening of the transverse axis of the range by the enormous tangential pressures that orogenic blocks of indefinite height could have been produced. Overthrusting, upthrusting, folding, mashing, and igneous intrusion have often occurred on such a scale, that were it not for other and inhibiting causes, differential elevations perhaps forty or fifty thousand or more feet in relative height might have resulted. No geologist believes that local blocks of such height have entered into the construction of any terrestrial range. Erosion during the absolutely slow, though relatively rapid, growth of the range has often been appealed to as sufficient to explain the lack of such heights in even the youngest alps of the world. But not sufficient emphasis has been placed on the quite different control of isostatic adjustment accompanying and following the paroxysmal uplift of orogenic blocks. Single steep slopes of possibly thirty thousand feet might, indeed, then exist if they were underlain by the strongest granite, which likewise formed the underpinning of the whole adjoining district, that granite being throughout at the temperatures of ordinary rock-crushing experiments. But such towering masses are highly improbable for weaker rocks which would crush down under the supposed conditions, and wholly impossible for mountain blocks overlying material as plastic as that which composes the original basement of an alpine range. The strength of the main mass of the range is diminished by the inevitable rise of subsurface temperatures with crumpling and mashing. It is the rule with alpine ranges that intrusions of hot magma on a huge scale either accompany or very soon follow the chief paroxysms of folding. In either case, and not only over the areas where denudation has exposed the intru-

sives, but also over much wider areas about the downwardly expanding bases of the batholiths, the heat of the intrusions still further increases the plasticity of the basement on which the mountains are growing. The weakness of the underpinning is further manifest in the case of such ranges as the Cascades or the Coast Range of British Columbia, so largely formed of granitic magma injected in a highly plastic, if not thoroughly fluid, state during or just after the last great period of plication in those ranges.

The conclusion seems unavoidable that the tendency of tangential force to erect orogenic blocks projecting much higher into the air than Mount Everest itself is operative only up to a certain critical point. Beyond that point the increasing weight of the growing block and the increasing plasticity of its basement call in another kind of movement due to the gravitational downcrushing of the block. As a whole, or in fragments separated from each other by normal faults, the block will assume a shape and position suitable to static equilibrium for the whole range. The range might conceivably find that equilibrium when the entire uplift has attained the form of an elongated arch accented by already roughly accordant mountain summits. At any rate, subequality of height might characterize large areas.

This whole phase of gravitational adjustment forms a problem clearly indeterminate in the present state of geological physics. Critical laboratory experiments have yet to be devised, and careful, special field-work devoted to the problem, before it can attain even an approximate solution. So far as it goes, however, gravitational adjustment of the kind just described aids all the other processes tending toward summit-level accordance.

3. Hypothesis of original rough accordance, due to differential erosion during the period of alpine plication.—Co-operating with isostatic adjustment is the effect of the special erosive attack on each rising block from the moment it once begins to dominate its surroundings. On the average, the forces of weather and waste are most destructive on the summits of this time, as they shall be through all the subsequent history of the range as an alpine relief. Denudation is in some direct ratio to the height of uplift. Higher summits are thereby reduced, while lower ones are still growing under the stress of mountain-building. How far erosion thus checks the upward growth

of the rising massifs probably cannot be measured, but such differential destruction must develop still further the rough summit-level accordance already in part established by isostatic adjustment.

4. *Conclusion.*—The downcrushing of higher, heavier blocks with the simultaneous rise of their lower, lighter neighbors, coupled with the likewise simultaneous, specially rapid loss of substance on the higher summits, form a compound process leading toward a single, relatively simple result. In both the architecture and the sculpture of her alpine temple, Nature decrees that its new domes and minarets shall not be indefinitely varied in height. Such accordance as they have among themselves will be preserved and accentuated as her chisels fashion new details on the building. The accordance of the present time in any alpine range is in part inherited from what, in this paper, has been called the "original" form of the range. The original form meant a first approximation to the result; the later, spontaneous modification of that form means a second approximation to perfect accordance.

The composite explanation.—In passing to an analysis of erosion events following the epoch of folding, we are, therefore, illustrating the cumulative forces of all the hypotheses so far announced as alternative with, and as against, the peneplain hypothesis for truly alpine ranges. By the peneplain hypothesis, the accordance of summit-levels was most perfect in the initial stage of the physiographic cycle begun by the upwarping of the peneplain; by that hypothesis mature dissection of the range tends to destroy something of the initial accordance. The alternative, composite explanation, already in part outlined, involves the conclusion that the accordance tends to become more and more perfect as the stage of mature dissection of the newly folded range is reached. The question remains whether the accordance inherited from the forms original from the epoch of plication may be so much further developed by subsequent erosion in the physiographic cycle initiated by that plication, as to give the amount of accordance actually observed in the existing range. If the answer be affirmative, the second inquiry becomes imperative as to the relative merits of the peneplain and composite hypotheses when applied to individual ranges. For reasons given on a previous page, the second inquiry is not specially raised in the present paper.

II. THE SPONTANEOUS DEVELOPMENT OF SUMMIT-LEVEL ACCORDANCE

1. *Spontaneous development by isostatic adjustment.*—The last paroxysm of crumple and upthrust in the young alpine range has occurred. Henceforth its forms are to be determined chiefly by erosive processes—yet not altogether so. Several authors have suggested that the leveling influence of gravity is not only manifest in the piecemeal carriage of rock fragments out to the piedmonts, or finally to the sea; but that also the very accordance of summit levels is in large part related to gravitational adjustment on a large scale.¹ Where, for any cause or causes, denudation significantly lowers a localized area of the range faster than neighboring areas of the same altitude, the former area will tend to rise, the surrounding region to sink, so as to reproduce conditions of equilibrium in the range. This view entails belief once again in the principle of isostasy. It must be admitted that the ground has only been broken in the important field of inquiry as to crustal sensitiveness. The harvest of field and experimental observations has not yet been reaped in volume sufficient to enrich geological science with definite knowledge on the matter. But such facts as the apparent isostatic recoils of the earth's crust after the melting away of the Scandinavian, Labrador, and British Columbia Cordilleran ice-caps, and the notable increase of dips at the feet of the High Plateaus of Utah and Arizona, as described by Major Dutton², are among those already recorded in favor of a sympathetic entertaining of the isostatic doctrine. The appeal to the principle in the present case is all the more worthy because of the long continuance of the special plasticity belonging to the very slowly cooling basement of a recently folded alpine range.

2. *Metamorphism and igneous intrusion in relation to the degradation of mountains.*—It is a truism that the rocks of any alpine range vary enormously in composition and structure. It is quite as true that their resistance to weathering and wasting is far less variable. In hundreds of square miles together, the geologist may map gneisses, schists, granites, diorites, marbles, quartzites, or ancient lavas, several or all of these occurring in great masses, and yet he may not be able to ascertain by manifest field evidence that any one of the

¹ See discussion in Penck's *Morphologie der Erdoberfläche*.

² *Monograph II*, U. S. Geological Survey (1882), p. 47.

formations is more resistant to the weather than an adjacent formation. That experience is common in the alpine districts where accordance of summit levels has been described. The implication is that the real differences in power to resist attack are of a low order among the rocks of these districts. The writer has often been struck with this fact in the course of field-work in the Coast Range and Selkirks of British Columbia. There, as generally, the phenomenon must be attributed mainly to wholesale metamorphism. This relative homogeneity among the rocks must be regarded as playing an important part in the preservation of summit-level accordance. Whether inherited or not, accordance will be clearly favored by homogeneity.

Secondly, the original upper surface of the zone of intense metamorphism may be conceived as much less uneven than the outer surface of the original range. Mr. Van Hise has shown that pressure is the principal control in the metamorphism of the zone of rock-flow.¹ In the present case, pressure is applied by tangential force and by the weight of individual massifs. The former is in dominant control, as shown by the generally steep dips of planes of schistosity. The lines of force in the tangential pressure are, on the average, not far from horizontal. In the later stages of the period of plication the master-lines of that force pass beneath structural depressions in the range. During the same time constructional massifs will largely escape the maximum squeezing which affects their bases. The weight of each massif will, however, cause the metamorphism to extend upward locally in some degree. The upper surface of the metamorphic core of the massif will have a flatter and, probably, a more regular profile than the rugged land surface above. The composition of the two forces due to weight and tangential pressure should, then, tend to produce a relatively simple upper surface for the whole zone of metamorphism. The surface will be a flat arch as a whole, but locally bearing subordinate domes of low curvature. Along with these subordinate domes must be others of similar low curvature due to the thermal metamorphism of batholiths.

Many of the great intrusive bodies of alpine ranges had originally themselves a demonstrably dome-like form with broad, flattish tops.

¹ *Monograph XLVII*, U. S. Geological Survey (1904), p. 43.

The foregoing statement of a difficult theme is brief, but it suffices to suggest the bearing of metamorphism and intrusion on the question of accordance. In what has been defined as its original state, an alpine range was composed of a hard, comparatively homogeneous core covered with a relatively thin veneer of already somewhat eroded, unmetamorphosed rock. The core is to be conceived as having an upper, limiting surface, with the form of a long, flat arch bearing subsidiary, low, broad, boss-like arches and domes. The erosion of the unmetamorphosed cover will go on apace. The erosion of the core, the main mass of the range, will progress much more slowly. Erosion may thus sweep away wide areas of the cover before the individual mountains between cañons sunk in the core have suffered significant loss of height by denudation. In such areas accordance of summit levels would henceforth be expected because of the original flattish tops of the core, and because of the comparative homogeneity of the core-rocks. For the same reasons, accordance among the summits of mountains cut out of a granite batholith would be expected. Where, however, the granite is distinctly harder than the surrounding metamorphics, there would not be simultaneous accordance with the summit levels of the metamorphic mountains, except for causes other than the two just described. As the composite explanation of accordance is further outlined, it will be seen that such other causes may operate effectively in some cases. Yet the common, special dominance of granite peaks in a truly alpine range agrees as well with the composite explanation as it does with their reference to the class of monadnocks on the peneplain theory.

3. *The influence of local glaciation on summit altitudes.*—Hitherto no detailed distinction has been necessary among the varied phases of erosion. All subaërial agencies of destruction combine their effects to establish so much of summit-level accordance as is due to erosion with consequent isostatic adjustment. Each of the agencies may take a part in the uncovering of the hard, metamorphic core of the range. Throughout the entire history of the range, however, special kinds and conditions of denudation independently do important shares of work in trimming the range to uniformity or accordance of summit levels. To ascertain the value of their work we must take the highland view. A few decades ago, when the power

of river corrosion was first adequately realized, the lowland view of earth sculpture became fruitful. It has led to the correct interpretation of land forms in every continent. Still later, the highland view that the alps of the world owe much of their form to conditions of erosion quite peculiar to high mountains, was first clearly taken by Penck, Dawson, Richter, and others. That their generalization came later than the brilliant statement of general erosion by Gilbert and Powell is natural, for man is a dweller in the lowlands; but science must know no such subjectivity. In the future the highland view must be sharpened and extended.

Local glaciers are characteristic of lofty, alpine mountains. High-lying cirque glaciers exist today by the hundreds in the Swiss Alps, by the thousands in the alps of British Columbia and Alaska. Pleistocene glaciers in vastly greater number and erosive power covered those same regions and, in fact, all the others where summit-level accordance in really alpine mountains has been described. Is there any connection between such glaciation and accordance?

The interesting problem of the origin of cirques or corries is not yet fully solved, but that they, by a vast majority, have been chiefly formed through glacial excavation is certain. In each glacier there are two loci of maximum erosion; one at the head of the glacier where the great *bergschrund* separates the ice from the solid rock of the head-wall; the other beneath the central zone of the glacier itself some distance upstream from the foot of the glacier. One result, noteworthy in the present connection, is to drive the head-wall of the growing cirque farther and farther into the mountain. In the nature of the case, it will be the higher peaks which are most vigorously attacked. From every side, it may be, comes the attack on the massif which, for any cause, specially projects above the general level of the range. Owing to the rapidity of the ice-erosion, that summit must tend to fall and reach something like accordance with its formerly lower, unglaciated or but lightly glaciated neighbors.

There seems to be no possible doubt that existing glaciers are thus working favorably with all the other methods of spontaneously producing summit-level accordance. How much more important has been the product of ancient glaciations in Europe and in America! Richter even makes local glaciation of the Pleistocene period

responsible for most of the peaked and serrated topography of the Swiss mountains. He supposes that in pre-Pleistocene times the range had the comparatively smooth, flowing profiles of well-graded mountains; that the present ruggedness is mostly due to the recession of head-walls in cirque-making.¹ The view may be extreme, but it illustrates the importance which the distinguished European physiographer attaches to the work of local glaciers. Their gnawing action is just as manifest about the countless glacier-beds among the highest peaks and sierras of the Rockies, Selkirks, and Coast Range of British Columbia, of the Washington Cascades, of the mighty ranges of Alaska. In all these fields the highest peaks and ridges long suffered specially powerful attack, as they alone stood high enough to wear the fatal belts of *bergschrund*. During the ice period, they were nunataks and lost substance like nunataks; the loftiest peaks losing most, the lower ones with less linear extent of *bergschrund*, losing proportionately less. Peaks and ridges not penetrating the general surface of the Cordilleran glacier lost nothing by special *bergschrund* attack.²

It is certain that this differential erosion was long continued during the Pleistocene period in each of the ranges where accordance of summit levels has been discussed. There is every reason to suppose that like conditions and like results would characterize still earlier glaciations.

For the present purpose it is not necessary to inquire as to the deepening or other modification of main valleys in the range. Important as may be such valley changes to the future scenery of the range, they cannot have anything like the same control over summit altitudes as the direct trimming down of the summits by glacier heads. Moreover, head-wall recession among the higher summits continues throughout the whole epoch of glaciation; the excavation of the main valleys occurs only during maximum glaciation.

In summary, then, it may be said that partial explanation for

¹ Petermann's *Mittheilungen, Ergänzungsheft* No. 132, 1900.

² Compare the views of W. D. Johnson and G. K. Gilbert, as announced in the *Journal of Geology*, December, 1904. The special glacial attack on the highest summit of the Big Horn Range (Cloud Peak) is excellently illustrated in the well-known *aper* by Matthes, *Twenty-first Annual Report, U. S. Geological Survey, Part II, 1899-1900*, Plate XXIII.

summit-level accordance is to be sought in a special, characteristic control of alpine climates. In general, the climate of high levels is a glacial climate. In general, glacial erosion is very great and the bulk of it is high-level erosion. In general, local glaciers and glacial erosion are most abundant and long-lived about the highest summits. One net result of glaciation is to cause the specially rapid wastage of those summits and to produce rough accordance among the peaks.

4. *The influence of the forest cap on summit altitudes.*—Climate not only breeds glaciers in the high levels of an alpine range; it normally determines a more or less well-defined tree-line. The treeless zone is always more extensive in area than the glacier-bearing zone, but the upper limit of trees is often not far from coincident with the lower limit of the zone of cirque glaciers. It is logical to find here a place for the theory that widespread accordance of summit levels in an alpine range is related to the differential rate of erosion above and below tree-line. The theory is so well known that it needs no special detailed statement in the present paper. Let it suffice to recall the principal reasons why denudation is faster above tree-line than below, and once more note the inevitable conclusion from that fact. Again we must take care to adopt the highland view of erosion. It cannot be too strongly emphasized that the conditions of rock destruction and transportation are vastly different from what they are at lower levels. It is only partially correct to discuss in terms of falling water the degradation of mountain slopes, whether tree-covered or not. Their degradation must chiefly be discussed in terms of falling rock-waste. In the lowlands stream corrosion has its maximum of destructive influence. Among the high mountains stream corrosion has a minimum of destructive influence. The analysis of high-mountain degradation deals, on the one hand, with the methods of rock-disintegration, and, on the other hand, with the methods of carrying the resulting waste out to the lowlands. The complete analysis waits on the discovery of quantitative data. We have here another instance of the need of sharpening and extending the highland view. Yet the qualitative data already recorded leave no doubt as to which zone is the more rapidly degraded.

a) *Disintegration of rock.*—A striking proof that Anglo-Saxons have only recently begun to take the highland view appears in the

lack of a commonly used English equivalent for the German word *Felsenmeer*. Equally striking is the fact that very few physiographic textbooks even mention one of the most characteristic and widely exemplified features of alpine mountains. Frost-action is, of course, chiefly responsible for the wonderful chaos of broken rock above tree-line. The *Felsenmeer* is itself direct evidence of exceptionally rapid disintegration. At many points the blocks of the rock-chaos are in special danger of being swept away by avalanches, or of more slowly moving valleywards by the powerful thrusting action of freezing water. The development of the *Felsenmeer* means a vast increase of rock surface on which frost, changes of temperature, and all the other chief methods of weathering, and therewith destruction, can act. Below tree-line an all-mantling *Felsenmeer*, because of the forest blanket, is forbidden. Much of the broken rock below tree-line is exotic, having fallen from the treeless zone. The indigenous *Felsenmeer* below the tree-line is chiefly concentrated beneath cliffs, and is a vanishing quantity when compared with the immense rock-chaos above. Both as an evidence of incomparably more rapid frost attack above tree-line than below, and as a condition for more effective attack by agents other than frost, the *Felsenmeer* is significant.

b) *Removal of rock-waste*.—On the other hand, the streaming of weathered material down the slopes is, other things being equal, probably several times more rapid in the treeless zone than below it.

(1) The direct beat and *wash of the rain* have practically negligible effect on waste-removal below tree-line. The power of heavy rain washing the treeless zone, either in the derived form of rills or as a sheet flood, is manifest to anyone who has experienced a good shower above tree-line.

(2) During the last two field-seasons the writer has for the first time become conscious of the importance of *burrowing mammals* in preparing loose rock-waste for speedy transit to the valleys. In the western Cordillera field-mice, gophers, moles, marmots, bears, and other species are each year doing an immense geological work. There can be no exaggeration in saying that these burrowers annually turn over hundreds of thousands, if not millions, of tons of soil or disintegrated rock in either the Coast Range or the Selkirk Range of British Columbia. Such work is of relatively little importance

where mounds or fillings of snow tunnels are protected by trees overhead. It is very different above tree-line, where even the weak veneer of turf is broken in the burrowing, and where the millions of mounds or tunnel-casts are exposed to every agent of transportation.

(3) The transporting efficiency of *wind* in the treeless zone of lofty mountains has, on the whole, been more emphasized by European observers than by those of America. So far as this is the case, Europeans have come nearer to the highland view than we have in this country. The summer quiet of alpine summits of itself gives a most deceptive idea of the power of wind in the heights. During the other seasons winds of almost hurricane violence are far from uncommon, if we can generalize from the limited instrumental data so far issued from high-lying observatories. We may believe that dust, sand, and fine gravels are so rare above tree-line largely because of such winds. For obvious reasons, sand-blasting there plays no such rôle as it does in the sculpturing of rock-forms in lowland deserts; but transportation by the wind is another influence placing in strong contrast the conditions of erosion in the regions above and below tree-line.

(4) Erosion and transport through *avalanches* are enacted in both the treeless and the forested zone. In the lower zone the destruction wrought by a great avalanche may be great, but it is largely a ruin of tree-trunks. In the lower zone the avalanche paths are tolerably well fixed from year to year, sparing much the greatest part of the forested area. In the treeless zone, avalanches have generally less momentum, but they are more numerous, less localized, and therefore more likely to find and sweep down loose rock débris. Above tree-line their ruin is wholly rock-ruin. It seems safe to conclude that snow-slides are more powerful agents of degradation above tree-line than below.

(5) The general streaming and cascading of rock-waste under the direct pull of *gravity* are evidently immensely more rapid in the treeless zone than where the strong vegetation mat binds humus, soil, and boulder to the bed-rock, though it be without perfect, ultimate success.

(6) The débris from the upper zone itself helps to protect the bed-rock of the lower zone. The very rapidity of general waste streaming above involves the slowing down of erosion below.

(7) The *chemical solution* of rock is, to be sure, probably more rapid beneath the forest-cap than it is above tree-line where the amount of vegetable acid is at a minimum. This cause may, however, be believed to do little toward counterbalancing the effect of the combined causes just enumerated. Erosion in alpine mountains takes place primarily by the removal of masses; in comparison, molecular transfer of rock material to the low grounds has but a very minor control.

Conclusion.—A review of the conditions of general degradation shows clearly its differential character above and below tree-line. Summits already reduced to the tree-line are bound henceforth to be stubborn against further erosion. Summits bearing a treeless zone are as clearly bound to continue wasting rapidly so as to tend to approach accordance of summit levels with their tree-covered neighbors. Since the glaciated zone of alpine mountains is, in general, well within the treeless zone, the special degradation due to local glaciers harmonizes with general erosion in the development of accordance.

5. *Accordance through river-spacing and gradation of slopes.*—A fifth method for the spontaneous development of summit-level accordance remains to be noted. The recent announcement and discussion of this explanation make it superfluous to present here more than the briefest analysis of the underlying ideas.¹

Professor Shaler in America and Professor Richter in Europe have independently shown that, as mature dissection of a region under normal climatic conditions is reached, rivers of the same class tend to become nearly equally spaced. In perfect maturity the slopes of the interstream ridges are graded from top to bottom. This gradation of the slopes draining into two adjacent, nearly parallel streams flowing in the same direction, produces a comparatively even longitudinal profile of the intervening ridge. The even crest of the ridge must be more or less sympathetic with the profiles of the streams below, and, down stream, slowly attain a lower and lower

¹ Cf. R. S. Tarr, *American Geologist*, Vol. XXI (1898), p. 351; N. S. Shaler, *Bulletin of the Geological Society of America*, Vol. X (1899), p. 263; W. S. T. Smith, *Bulletin of the Department of Geology*, University of Colorado, Vol. II (1899), p. 155; E. Richter, *Zeitschrift des deutschen und österreichischen Alpenvereins*, Vol. XXX (1899), p. 18; W. M. Davis, *American Geologist*, Vol. XXIII (1899), p. 207.

level. Local notches or cols may be gnawed in the ridge, but all the summits must be roughly accordant, though, of course, not uniform, in altitude. Other things being equal, the more mature the dissection, the more perfect the summit-level accordance; but the principle may be applied to alpine ranges. In those ranges the actual imperfect degree of accordance may often match the imperfectly matured state of dissection.

GENERAL CONCLUSION AND SUMMARY

The form of the preceding discussion has been analytical, but its main point has been to emphasize the synthetic nature of the process of mountain sculpture. Seven different conditions of erosion *work together* to produce accordance of summit levels in an ideal alpine range undergoing its first cycle of physiographic development. Isostatic adjustment and simultaneous, differential degradation of rising blocks tend to bring about rough accordance of summit levels in the range as "originally" formed. Later differential erosion and consequent further isostatic adjustment, the influence of metamorphism and intrusion, the sculpture due to high-level glaciation, the normal existence of a high-level tree-line, and, finally, the compound process of river-spacing and slope gradation—all these may combine their effects and render more perfect the accordance of levels inherited from the early, growing period of the range.

In an actual range, as distinguished from the ideal range, all seven of these conditions may not be present; the efficiency of those that are present make the special problem of that special range.

The composite explanation of accordance must always face the alternative explanation of the peneplain theory. The latter theory involves two physiographic cycles in the history of the range, and attributes summit-level accordance to inheritance from the initial, upwarped peneplain surface of the second, present cycle. Several of the chief conditions of erosion on which the composite explanation is based, tend, of course, to preserve the accordance of levels inherited from the peneplain.

The strength of each of the two explanations is so great that a decision as to which is true for a given alpine range may need nice discrimination. Nevertheless, the profound differences between the

two theories regarding the geologic and physiographic history of the range makes the decision of primary importance. The existence of broad, little-dissected plateaus remnant from a greater plateau nearly or quite coextensive with the range having internal structures of alpine complexity, is a positive criterion favorable to the peneplain theory. From such remnant plateaus must be distinguished the elevated shelves due to high-level glacial erosion; to wind erosion; to the local control of internal structure; or to changes in conditions whereby the floors of former, high-lying basins of erosion, through deformation or through the migration of divides, become the summits. Peneplain remnants must further be distinguished from the common, often broad, ridge-summit formed by the meeting of two gentle slopes where the low angles of the slopes are incidental to general gradation of the mountain above tree-line. Analogous forms on a much smaller scale are never absent from the ridges in bad land topography where there is no suggestion of peneplanation.¹

On the other hand, the remnant plateaus may not appear in the present topography of a range, and the accordance of summit altitudes may characterize peaks and serrate ridges only. Such accordance may give a comparatively even sky-line in the views from any dominating point, but the full force of the composite explanation of accordance as above outlined is directed against the reference of that even sky-line to the direct or inherited profile of an ancient, uplifted peneplain.

¹ G. K. Gilbert, *Geology of the Henry Mountains* (Washington, 1877), p. 122.